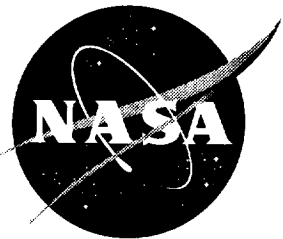


NASA Contractor Report 4549

Metabolic Rate Measurements Comparing Supine with Upright Upper-Body Exercises

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Abbreviations and Acronyms

| | |
|-----------------|---|
| ATSP | ambient temperature, pressure, saturated with water |
| BSA | body surface area |
| Btu | British thermal unit |
| CO ₂ | carbon dioxide |
| DCS | decompression sickness |
| EVA | extravehicular activity |
| ft | foot |
| h | hour |
| in-lb | inch-pound |
| kcal | kilocalorie |
| kp | kilopond |
| kPa | kilopascal |
| kpm | kilopond meter |
| L | liter |
| lb | pound |
| m | meter |
| N | newton |
| N ₂ | nitrogen |
| N•m | newton meter |
| O ₂ | oxygen |
| psi | pounds per square inch |
| RQ | respiratory quotient |
| SE | standard error |
| STPD | standard temperature, pressure, and dry |

INTRODUCTION

A number of ground-based studies have been conducted in an altitude chamber at the NASA Johnson Space Center to verify operational protocols for extravehicular activities (EVAs) that reduce the risk of decompression sickness (DCS) [9, 2]. During these studies, test subjects exercised using their upper-body limbs to simulate different EVA tasks at a level of 200 kcal/h. This level approximated the average energy expended during EVA on previous space flights [2].

To study the possible effect of microgravity on the incidence of DCS, a provocative investigation of DCS was conducted with subjects who were bed rested for 3 days prior to exercising their upper-body limbs supine in bed at a simulated altitude. The development of DCS symptoms during supine exercise by the bed-rest subjects was compared to that of control subjects during upright exercises [8]. During the study, it was essential that the work activities conducted at reduced pressure were comparable in both the supine and upright exercise groups.

The aim of this study was to measure the metabolic rates during both supine and upright exercise as previously documented [3]. Increases in metabolic rates during exercise and decreases in mechanical efficiency of the treadmill in space flights have been reported [1]. The purpose of this NASA Contractor Report is to document the ground-based study that tested the hypothesis that metabolic rates during supine and upright exercise are similar.

MATERIALS AND METHODS

Subjects

Six subjects (three males and three females) were tested. Each subject had a screening examination similar to an Air Force Class III physical examination, signed the NASA Human Research Consent Form, and completed a maximal exercise stress test prior to participating in the study.

Exercises

Three exercise stations, a hand-cycle ergometer (Model 194 EM Monark Cycle Ergometer, MacLevy Products Corp., Elmhurst, NY), a rope-pull device (Mini-Gym Model 180X Isokinetic Exerciser, Misanron Health and Fitness Systems, Inc., Independence, MO), and a torque wrench [3], were designed for two groups of identical subjects, those who were supine in bed and those who exercised upright (seated or standing) by the station. Each subject performed the supine or upright exercise at 4-minute intervals (assigned randomly) for a total of 60 minutes for each group. A minimum rest period of 1 hour was established between the supine and upright exercises. Two subjects did not complete the upright exercise portion of the study.

The protocol schedule (Table 1) allowed for a rotation every 4 minutes of each exercise station for two cycles (24 minutes) and two 4-minute rest periods (8 minutes). The hand-cycle ergometer was operated at a rate of 3 revolutions of the hand crank every 5 seconds for each hand (clockwise for the right hand and counterclockwise for the left hand), followed by a 5-second rest against a resistance of 0.5 kp (288 kpm) for both the upright and supine stations. While seated or supine, the rope-pull device was operated with hands together at a rate of two pulls to the waist every 5 seconds for a period of 4 minutes against a resistance of 11 kp (25 lb)

for a distance of approximately 0.7 m (758 kpm). During the second cycle, the rope was pulled twice with alternating hands every 5 seconds. The torque wrench was operated by holding the wrench in the right hand on each of four studs alternately pushing and pulling each holding for 5 seconds, repeating the movements for a 4-minute period at a work load of 35 Nm (3.6 kpm).^{*} The left hand was used during the second cycle. Flashing cadence lights indicated 5-second intervals. The subjects were monitored with an electrocardiograph (Mingograf, Siemens Medical, Stafford, TX) during exercise as a safety precaution.

Expired Gas Collection

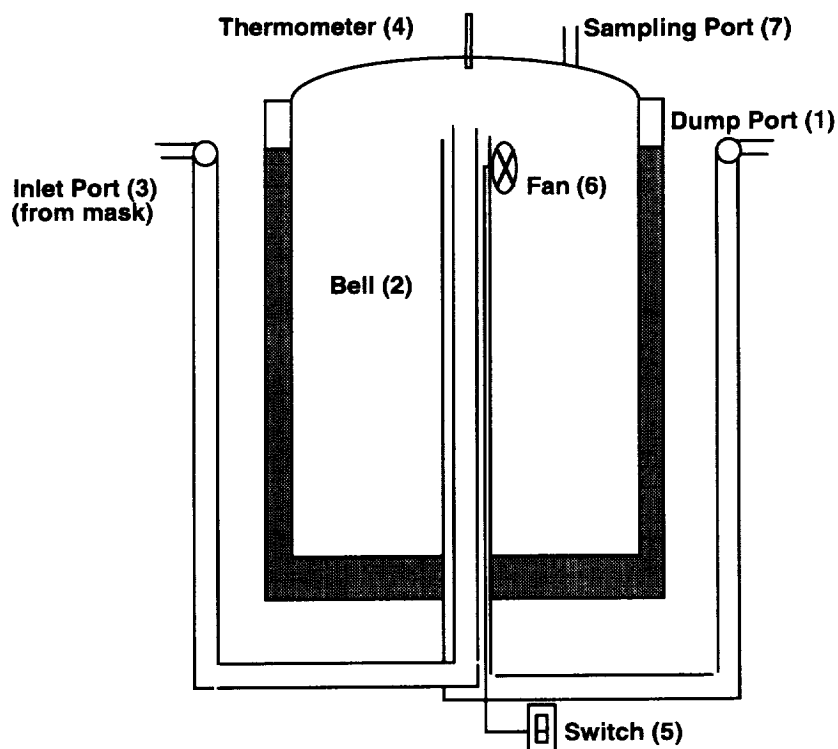
After a baseline measurement of the metabolic rate at rest and one rotation of the three exercise stations (for warm-up), the metabolic rate was measured twice at each exercise station during six 4-minute gas collection periods (24 minutes, Table 1).

Table 1. *Rotation protocol for the exercise stations and gas collection*

| <u>Time</u> | <u>Station/(Code #)</u> | <u>Procedure</u> |
|-------------|---------------------------|------------------------|
| -0:04 | Baseline | Expired Gas Collection |
| 0:00 | Hand-cycle ergometer (1) | |
| 0:04 | Right-hand torque (2A) | |
| 0:08 | Right-hand rope pull (3A) | Expired Gas Collection |
| 0:12 | Hand-cycle ergometer (1) | |
| 0:16 | Left-hand torque (2B) | |
| 0:20 | Left-hand rope pull (3B) | Expired Gas Collection |
| 0:24 | Rest | |
| 0:28 | Hand-cycle ergometer (1) | |
| 0:32 | Right-hand torque (2A) | Expired Gas Collection |
| 0:36 | Right-hand rope pull (3A) | |
| 0:40 | Hand-cycle ergometer (1) | |
| 0:44 | Left-hand torque (2B) | Expired Gas Collection |
| 0:48 | Left-hand rope pull (3B) | |
| 0:52 | Rest | |
| 0:56 | Hand-cycle ergometer (1) | Expired Gas Collection |
| 1:00 | Right-hand torque (2A) | |

The subjects breathed through a mouthpiece and two-way valve (Hans-Rudolph Co., Kansas City, MO) connected to a 120-liter gasometer (Collins, Inc., Boston, MA) for 3 to 4 minutes. The gasometer and the procedure are illustrated in Figure 1.

^{*}The resistances for the original exercise stations resulting in mean metabolic rates of 177 kcal/h \pm 21(SD) (702 Btu/h \pm 82[SD]) were 0.5 kp (4.6 N) for the hand ergometer, 11 kp or 108 N (25 lb) for the rope-pull, and 34 N•m (300 in-lb) for the torque station (J. Waligora, 1983, personal communications; see Appendix A).



Steps to collect expired gas

1. Turn knob (1) open and slowly lower the bell (2) to dump gas
2. Close knob (1)
3. Connect mouth-piece to the test subject
4. Turn knob (3) to open breathing tube to the gasometer inlet port
5. Fill the bell (2) of gasometer partially with subject's air
6. Switch on (5) the fan (6) for 10 seconds
7. Close inlet knob (3)
8. Turn open knob (1) and slowly lower the gasometer bell (2) to dump gas
9. Close knob (2)
10. Note initial volume from the scale (not shown) on data sheet
11. Turn knob (3) to open breathing tube to the gasometer inlet port
12. Start stop-watch
13. Observe that the bell rises and collects gas for exactly 4 minutes
14. Close inlet knob (3)
15. Remove mouthpiece from test subject
16. Note final volume from the scale and temperature (4) on data sheet
17. Switch on (5) the fan (6) for 10 seconds
18. Attach mass spectrometer line to the gas outlet (7)
19. Note percentage of N_2 , O_2 , and CO_2 on the data sheet
20. Dump remaining gas as in step 1

Figure 1. *Gasometer and procedure for collecting expired gas in a 120-liter gasometer*

The exact time was recorded. The volume of expired gas was calculated by subtracting the initial reading from the final reading on the gasometer scale that corresponded to the distance that the bell was displaced in the water at ambient temperature and pressure. A fan in the

gasometer was engaged for 10 seconds to mix the expired gas. The samples were analyzed directly for the percentage of oxygen, nitrogen, and carbon dioxide in the inspired and expired gas with a mass spectrometer (Model 1100, Perkin Elmer, Inc., Pomona, CA). The data record sheet is illustrated in Figure 2.

| | | | | | | | |
|---|---------------------------|-------|--------|----|----------------|----------------|-----------------|
| Name: _____ Sex: _____ Date: _____ | | | | | | | |
| Age: _____ Height: _____ Weight: _____ Body Surface Area: _____ | | | | | | | |
| Gasometer Factor=1.332 Atmospheric Pressure: _____ mmHg | | | | | | | |
| TIME (min) | GASOMETER READINGS (APTS) | | | | % EXPIRED GAS | | |
| *Code#/ Total Time | Initial | Final | Volume | °C | O ₂ | N ₂ | CO ₂ |
| Group | | | | | | | |
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| *Code number for the exercise station | | | | | | | |

Figure 2. *Data sheet for metabolic rate measurement*

The temperature of the gasometer was recorded for each measurement, and barometric pressure was recorded at the start of the experiment. The inspired air was sampled at the subject's mouthpiece, and the expired air was sampled from the gasometer through a small outlet valve. Before measurements were taken and in between subjects, any air remaining in the gasometer was purged by partially filling up the bell with the subject's air and discarding it.

Data Analysis [6]

All raw data were collected and stored in a data base; the following formulas were used to calculate each measurement, using Microsoft Excel Software (Microsoft Corp., Redmond, WA).

- Expired gas volume (L) at ambient temperature, pressure, saturated with water (ATPS)=[(final reading-initial reading)x1.332].
- Gas volume/min (ATPS)=(liters ATPS/duration of gas collection).

- Gas volume/min at standard temperature, pressure, and dry (STPD)=[(L/min ATPS)(273 °C/(273 °C ± °C of the gas))]/[(barometric pressure mmHg-wet vapor pressure mmHg)/760 mmHg]. The value for the vapor pressure of wet gas is listed in a Table 2 [6].

Table 2. Vapor pressure (P_{H_2O}) of wet gas at laboratory temperatures (°C)

| °C | P_{H_2O} | °C | P_{H_2O} |
|----|------------|----|------------|
| 20 | 17.5 | 26 | 25.2 |
| 21 | 18.7 | 27 | 26.7 |
| 22 | 19.8 | 28 | 28.4 |
| 23 | 21.1 | 29 | 30.0 |
| 24 | 22.4 | 30 | 31.8 |
| 25 | 23.8 | 31 | 33.7 |

- Volume O₂ consumption (L/min)=[L/min STPD][(%N₂ expired/%N₂ inspired)(%O₂ inspired-%O₂ expired)/100].
- Volume CO₂ production was calculated by [L/min STPD][(%CO₂ expired-%CO₂ inspired)/100].
- Respiratory quotient (RQ)=(L/min CO₂ produced/L/min O₂ consumed).
- The metabolic rate in kcal/L O₂ consumed came from Table 3 [6] using the RQ.
- The metabolic rate in kcal/h=[(L/min O₂ consumed)(kcal/L O₂ consumed)][60 min].
- The body surface area (BSA) of each subject was calculated from the weight and height using sliding scales [6].
- Input of energy (kpm/h)=(mean metabolic rate in kcal/h)(426.4 kpm/kcal)
- Mechanical work output (kpm/h)=(mechanical work output/4 min)(60 min/h)
- Percentage of mechanical efficiency=(mechanical work output)/(input of energy)
- Net energy expended (kcal/h)=(energy expended during exercise)-(baseline energy expenditure)
- Energy expended during exercise due to standing/sitting=(energy expended during upright exercise)-(energy expended during supine exercise)

The metabolic rates (kcal/h), RQ values, mechanical efficiency, and net energy input from each exercise station for supine and upright-control subjects were compared statistically using one-factor analysis of variance and post hoc F-tests with Statview II Software (Abacus Concept, Inc.,

Berkeley, CA). A value of $p < 0.05$ was chosen to indicate a significant difference between the groups and rejection of the null hypothesis. CA-Cricket Graph III (Computer Associates International, Inc., San Jose, CA) and MacDraw II (Clariscorp., Santa Clara, CA) were used to illustrate the figures.

Table 3. *Nonprotein respiratory quotient (RQ) relative to oxygen consumed (kcal/L)*

| <u>RQ</u> | <u>Oxygen Consumed</u> | <u>RQ</u> | <u>Oxygen Consumed</u> |
|-----------|------------------------|-----------|------------------------|
| 0.707 | 4.686 | 0.86 | 4.875 |
| 0.71 | 4.690 | 0.87 | 4.887 |
| 0.72 | 4.702 | 0.88 | 4.899 |
| 0.73 | 4.714 | 0.89 | 4.911 |
| 0.74 | 4.727 | 0.90 | 4.924 |
| 0.75 | 4.739 | 0.91 | 4.936 |
| 0.76 | 4.751 | 0.92 | 4.948 |
| 0.77 | 4.764 | 0.93 | 4.961 |
| 0.78 | 4.776 | 0.94 | 4.973 |
| 0.79 | 4.788 | 0.95 | 4.985 |
| 0.80 | 4.801 | 0.96 | 4.998 |
| 0.81 | 4.813 | 0.97 | 5.010 |
| 0.82 | 4.825 | 0.98 | 5.022 |
| 0.83 | 4.838 | 0.99 | 5.035 |
| 0.84 | 4.850 | 1.00 | 5.047 |
| 0.85 | 4.862 | | |

RESULTS

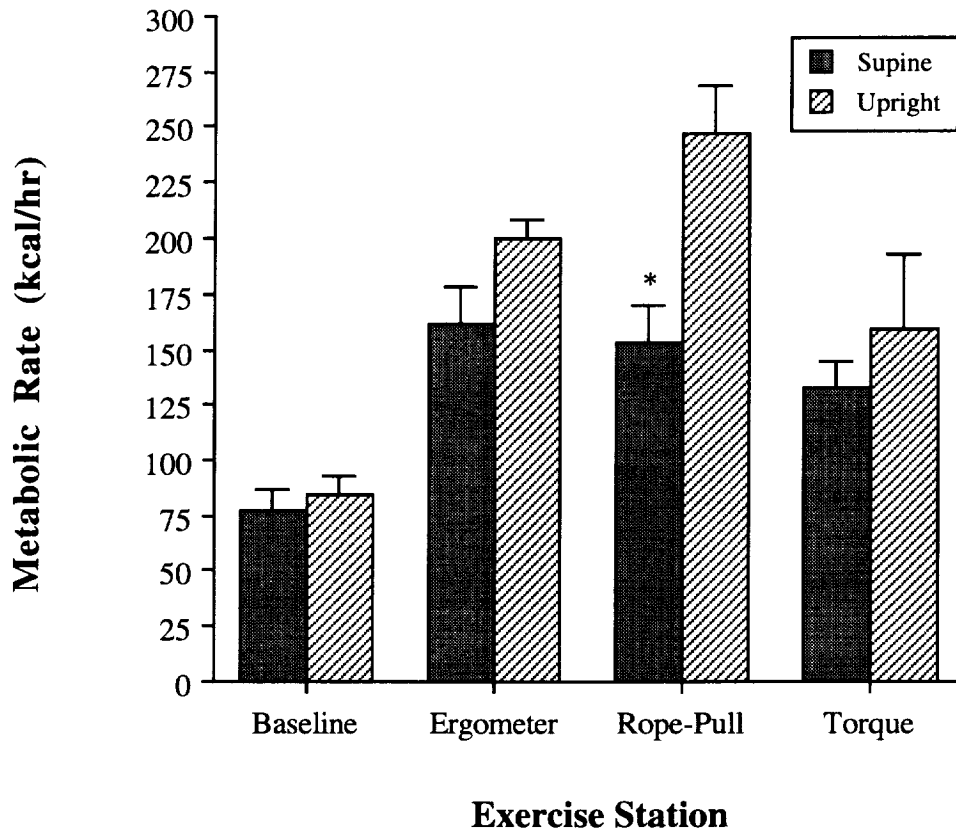
All the data were collected, recorded, and averaged for each exercise station. The baseline and average values each combined for the supine exercises and for the upright-control exercise stations were calculated for each subject and these data are listed in Appendix B.

The mean metabolic rates (kcal/h) during supine (n=6) and upright-control (n=4) exercise stations are listed in Table 4 and illustrated in Figure 3.

Table 4. *Comparison of metabolic rates (kcal/h) between supine and upright-control exercise groups (Mean \pm SE)*

| | <u>Baseline</u> | <u>Ergometer</u> | <u>Rope-Pull</u> | <u>Torque</u> |
|---------|-----------------|------------------|-------------------|------------------|
| Supine | 76.9 \pm 10.3 | 161.6 \pm 16.8 | 153.5 \pm 16.6* | 132.3 \pm 11.8 |
| Upright | 83.8 \pm 9.3 | 200.4 \pm 8.4 | 247.0 \pm 21.7 | 158.6 \pm 34.2 |

* $p < 0.05$ comparing supine to upright group



* $p < 0.05$

Figure 3. Comparison between mean metabolic rates (kcal/h) during supine ($n=6$) and upright ($n=4$) exercising, before exercise (baseline) and for each exercise station

Although the means of the metabolic rates during supine exercise were consistently lower, only those during the rope-pull exercise were statistically significant.

The RQ means for all groups were not significantly different (Table 5).

Table 5. Comparison of RQ values between supine and upright-control exercise groups (Mean \pm SE)

| | <u>Baseline</u> | <u>Ergometer</u> | <u>Rope-Pull</u> | <u>Torque</u> |
|---------|-------------------|-------------------|-------------------|-------------------|
| Supine | 0.861 \pm 0.049 | 0.861 \pm 0.035 | 0.877 \pm 0.036 | 0.881 \pm 0.032 |
| Upright | 0.901 \pm 0.065 | 0.876 \pm 0.037 | 0.839 \pm 0.101 | 0.851 \pm 0.026 |

The relationship between the body surface area of the subjects and the metabolic rate was examined by simple regression (Figure 4). Although a positive trend was observed, it was not statistically significant nor was there a difference between the two groups, $r^2=0.391$ for supine and $r^2=0.365$ for upright control).

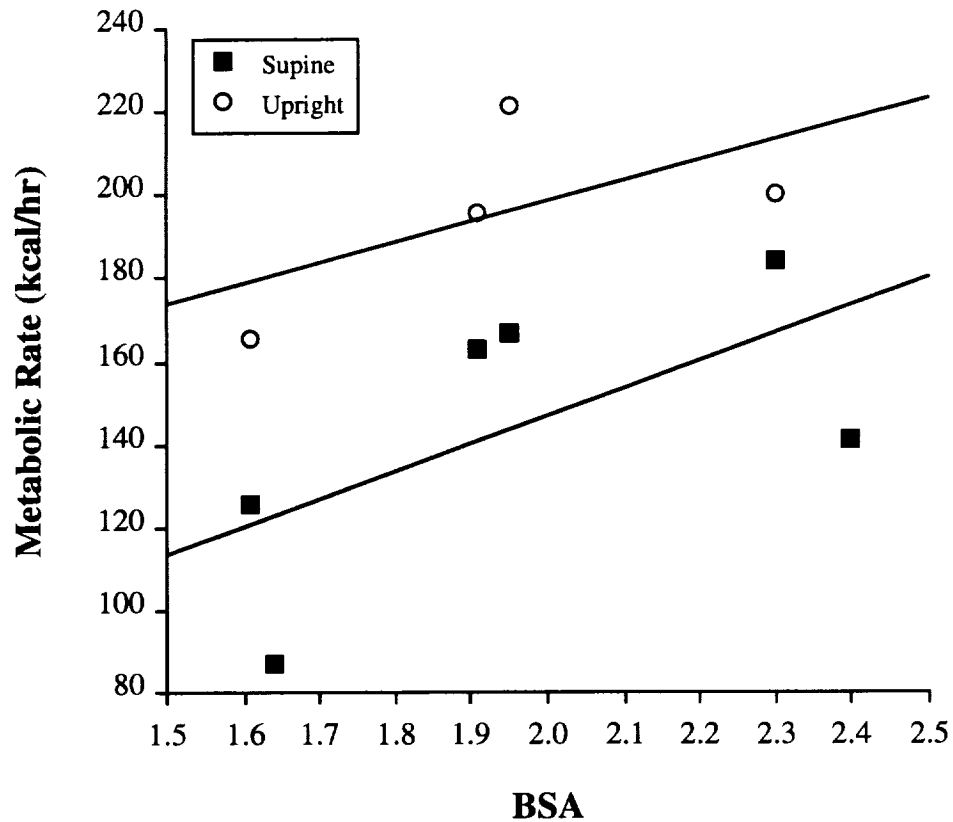


Figure 4. *The relationship between body surface area (BSA) and metabolic rate during supine and upright exercise*

The total work output (kpm/h) and total energy input (kpm/h) were calculated for the upright and supine exercise stations (Appendix B). The percentage of mechanical efficiency for each exercise station is listed in Table 6. The mechanical efficiency of the supine rope-pull exercise group was significantly higher than that of the upright rope-pull exercise group.

Table 6. *Comparison of percentage of mechanical efficiency between supine and upright-control exercise groups of each exercise stations (Mean \pm SE)*

| | <u>Ergometer</u> | <u>Rope-pull</u> | <u>Torque</u> |
|---------|------------------|------------------|---------------|
| Supine | 6.0 \pm 0.7 | 15.0 \pm 0.7* | 4.8 |
| Upright | 5.0 \pm 0 | 11.0 \pm 1.08 | 3.8 |

* $p < 0.05$ comparing supine to upright group (n=4 for each group)

The net energy expenditures comparing supine to the upright exercise stations are listed in Table 7. Although the net energy input was lower in the supine exercise groups, only the difference for the rope-pull station was statistically significant. Therefore, an additional mean energy expenditure of 112 kcal/h was required for the upright rope-pull exercise station.

Table 7. *Comparison of net energy input (kcal/h) between supine and upright-control exercise groups (Mean \pm SE)*

| | <u>Ergometer</u> | <u>Rope-pull</u> | <u>Torque</u> |
|---------|------------------|------------------|---------------|
| Supine | 89 \pm 14 | 64 \pm 18* | 67 \pm 25 |
| Upright | 129 \pm 9.4 | 176 \pm 20 | 91 \pm 35 |

* $p < 0.05$ comparing supine to upright group

DISCUSSION

The prevention of DCS is a major concern for the NASA's Space Flight Medical Program during EVA in Space Transportation System flights and Space Station Freedom missions. DCS is due to the formation of a free gas phase in tissues during decompression and may be exhibited in subjects as joint pain (bends) or neurological impairment and other symptoms. This concern is based on marked changes in pressure from the Shuttle cabin pressure at 101.3 kPa (14.7 psi) to that of the EVA suit at 29.64 kPa (4.3 psi). DCS risk is reduced by washing nitrogen from the tissues with breathing oxygen and by staged cabin and airlock decompression to 29.6 kPa (4.3 psi) prior to EVA [9, 2].

It is known that exercise at altitude increases the risk of DCS [4, 5], but little is known about the combined effect of in-flight exercise and EVA on the risk of DCS. A preliminary ground-based study indicated that subjects who performed 30 minutes of exercise daily for 3 days prior to a chamber flight that included simulated-EVA exercises did not have an increased risk of DCS [4]. Another study was designed for bed-rest subjects exercising at a simulated altitude (6400 m [21,000 ft]). A reduction in the incidence of venous gas-phase formation and DCS was observed in individuals of the bed-rest exercise group as compared to those of the upright-control exercise group [8].

Although the work activities were similar in the altitude exposures with and without simulated microgravity, this study was designed to determine whether the metabolic rates during both the bed-rest and ambulatory-control exercises were approximately 200 kcal/h. Significant differences in metabolic rates for the supine group as compared to upright-control group for the rope-pull device were demonstrated. Although the differences were small, the finding did not support the hypothesis (the null hypothesis stated that there is no significant difference in metabolic rates when exercising in either position, supine and upright). This indicated that exercising while supine may require different energy expenditures than upright exercising. Eliminating the data of two subjects who did not complete the upright-exercise portion of the study did not alter the statistical results, except for comparing the mechanical efficiencies between the supine and upright rope-pull groups. The numeric values of the mechanical efficiencies were much smaller than those of the metabolic rates, probably skewed by large variations within the small group of subjects.

Components that affect the daily energy expenditures of a subject depend on the resting metabolic rate (60 to 70 percent), the thermic effect of eating (approximately 10 percent), and the thermic effect of physical exercise (15 to 30 percent) [6]. The resting metabolic rate of an individual is related proportionately to the body surface area and dependent on the age and

gender. Although the number of subjects was small, these variables did not affect the results of this study. The mean RQ values and the r^2 value for the correlation between metabolic rate and BSA did not vary significantly between the supine and upright-control groups. These RQ values indicated no differences between the groups in the caloric transformation of the subjects' diets. Since the same subjects participated in the supine and upright-control groups, these findings were expected and are now verified.

The mechanical efficiencies were calculated for each station, and a significant difference between the supine and upright rope-pull stations was observed. This may contribute, in part, to the differences in the metabolic rates. Since the net energy expenditure for the upright exercise stations was greater compared to that for the supine exercise stations, a small amount of additional energy may be required to exercise while standing or sitting as compared to that supine.

Factors that are postulated to result in reduced metabolic rates during supine exercises are as follows:

- The supine rope-pull exercise station may be mechanically more efficient than the upright-control rope-pull exercise station.
- Exercising upright may require additional energy that is not required while supine and is reflected in a decreased metabolic rate for supine exercises.

If critical, an increase in the mechanical work loads of the supine exercise stations may be necessary to maintain the required metabolic rate of 200 kcal/h.

Bed rest is an accepted model for microgravity [7]. Further studies on the effects of bed rest prior to supine exercise and exercise during microgravity are necessary to determine the factor(s) that may affect metabolic activity and to develop methods of compensating or accounting for gain or loss, if necessary. The relationship between supine exercising, metabolic rates, and the incidence of DCS during EVA also should be examined to determine the true risk of DCS in space flight.

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|--|--|
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Appendix A. Bends III Exercise Protocol for New Subjects and Metabolic Rate (BTU/hr)

| Subject Number | Weight (kg) | Exercise Type | Standing Rest (Btu/h) | All exercise (Btu/h) | All exercise rest (Btu/h) | Lying Rest (Btu/h) | Exercise Corrected to 75 kg (Btu/h) | Exercise & Rest Corrected to 75 kg (Btu/h) | Mini Gym Exercise 1 (Btu/h) | Crank Station Exercise 2 (Btu/h) | Torque Station Exercise 3 (Btu/h) |
|--|-------------|---------------|-----------------------|----------------------|---------------------------|--------------------|-------------------------------------|--|-----------------------------|----------------------------------|-----------------------------------|
| 1 | 78 | | | | | | | | | | |
| 2 | 80 | A | 580 | 707 | 648 | 470 | 663 | 607 | 628 | 715 | 780 |
| 3 | 75 | | | | | | | | | | |
| 4 | 98 | B | 520 | 902 | 838 | 648 | 690 | 641 | 943 | 784 | 979 |
| 5 | 67 | | | | | | | | | | |
| 6 | 95 | B | 516 | 733 | 671 | 489 | 578 | 529 | 722 | 667 | 809 |
| 7 | 66 | B | 321 | 686 | 653 | 554 | 782 | 744 | 681 | 641 | 737 |
| 8 | 79 | B | 489 | 770 | 711 | 593 | 731 | 675 | 818 | 722 | |
| 9 | 78 | A | 448 | 721 | 665 | 496 | 693 | 639 | 672 | 734 | 758 |
| 10 | 85 | A | 420 | 743 | 668 | 446 | 655 | 590 | 648 | 775 | 806 |
| 11 | 101 | B | 465 | 692 | 685 | 663 | 513 | 508 | 638 | 708 | 732 |
| 12 | 75 | B | 312 | 633 | 592 | 470 | 633 | 592 | 585 | 535 | 780 |
| 13 | 68 | B | 408 | 577 | 580 | 590 | 637 | 640 | 528 | 585 | 619 |
| 14 | 66 | A | 460 | 634 | 597 | 487 | 720 | 679 | 631 | 748 | 487 |
| 15 | 95 | | | | | | | | | | |
| 16 | 77 | A | 468 | 586 | 568 | 516 | 576 | 553 | 468 | 609 | 681 |
| 17 | 72 | A | 468 | 733 | 673 | 492 | 767 | 701 | 615 | 765 | 821 |
| 18 | 70 | B | 450 | 714 | 671 | 540 | 765 | 718 | 734 | 724 | 686 |
| 19 | 64 | | | | | | | | | | |
| 20 | 80 | | | | | | | | | | |
| 21 | 80 | | | | | | | | | | |
| 22 | 95 | | | | | | | | | | |
| 23 | 79 | | | | | | | | | | |
| Mean | 80 | | 451 | 702 | 658 | 532 | 671 | 629 | 665 | 693 | 744 |
| ±SD | 11 | | 71 | 82 | 67 | 68 | 80 | 70 | 117 | 75 | 116 |
| ±SE | 2 | | 19 | 22 | 18 | 18 | 21 | 19 | 31 | 20 | 31 |
| Exercise 1: A type, right and left hand pull to 25 lb alternating every 5 sec. B type, both hands pull twice in 5 sec. | | | | | | | | | | | |
| Exercise 2: A type, right hand crank 3 times in 5 sec. B type, left hand crank 3 times in 5 sec. with 5 sec. rest between cranks. Resistance set 1/2 kp. | | | | | | | | | | | |
| Exercise 3: A type, right hand torque to 300 in•lb for 5 sec. B type, left hand torque to 300 in•lb for 5 sec. | | | | | | | | | | | |
| Ratchet ball also used. | | | | | | | | | | | |

Appendix B. Data Base to Calculate Body Surface Area, Average Metabolic Rates, Mechanical Efficiency, and Energy Input of Control Subjects Exercising at Site Level

| I.D.# | Activity Level | Exercise | Age | Sex | Wt (lb) | Wt (kg) | Ht (in) | Ht (m) | Body Surface Area (BSA) (m ²) | Average BMR* (kcal/m ² /h) | Estimated Resting Energy Output kcal/h | Initial Volume Trial 1 | Final Volume (ATPS) Trial 1 | Initial Volume Trial 2 | Final Volume (ATPS) Trial 2 | Gas Volume (L) (ATPS) (calc) Trial 1 | Gas Volume (L) (ATPS) (calc) Trial 2 |
|-------|----------------|-----------|-----|-----|---------|---------|---------|--------|---|---------------------------------------|--|------------------------|-----------------------------|------------------------|-----------------------------|--------------------------------------|--------------------------------------|
| 5 | Upright | Baseline | 25 | F | 198 | 90 | 64 | 1.63 | 1.95 | 36 | 70 | 5 | 18 | | | 17.32 | |
| | | Ergometer | | | | | | | | | | 7.2 | 62.1 | 5.9 | 53.5 | 73.13 | 63.40 |
| | | Rope-Pull | | | | | | | | | | 7.3 | 77 | 4.9 | 62.6 | 92.84 | 76.86 |
| | | Torque | | | | | | | | | | 6.4 | 38.5 | 6.7 | 34.9 | 42.76 | 37.56 |
| | | Post | | | | | | | | | | 5.6 | 24.9 | | | 25.71 | |
| | Upright | Exercise | | | | | | | | | | 6.97 | 59.20 | 5.83 | 50.33 | 69.57 | 59.27 |
| | Supine | Baseline | 25 | F | 198 | 90 | 64 | 1.63 | 1.95 | 36 | 70 | 6 | 21.8 | | | 21.05 | |
| | | Ergometer | | | | | | | | | | 6.3 | 51.9 | 6.1 | 50.3 | 60.74 | 58.87 |
| | | Rope-Pull | | | | | | | | | | 5.9 | 48.1 | 5.4 | 45 | 56.21 | 52.75 |
| | | Torque | | | | | | | | | | 6.5 | 33.8 | 5.3 | | 36.36 | |
| | | Post | | | | | | | | | | 4.9 | | | | | |
| | Supine | Exercise | | | | | | | | | | 6.23 | 44.60 | 5.60 | 47.65 | 51.10 | 55.81 |
| 6 | Upright | Baseline | 35 | M | 220 | 100 | 76 | 1.93 | 2.30 | 37 | 85 | 5.1 | 30.7 | | | 34.10 | |
| | | Ergometer | | | | | | | | | | 6.7 | 52.4 | 6.4 | 64.3 | 60.87 | 77.12 |
| | | Rope-Pull | | | | | | | | | | 6.2 | 52.7 | 6.9 | 48.7 | 61.94 | 55.68 |
| | | Torque | | | | | | | | | | 7 | 45.9 | 7.3 | 60.1 | 51.81 | 70.33 |
| | | Post | | | | | | | | | | 5.4 | 36.8 | | | 41.82 | |
| | Upright | Exercise | | | | | | | | | | 6.63 | 50.33 | 6.87 | 57.70 | 58.21 | 67.71 |
| | Supine | Baseline | 35 | M | 220 | 100 | 76 | 1.93 | 2.30 | 37 | 85 | 5.4 | 30.6 | | | 33.57 | |
| | | Ergometer | | | | | | | | | | 6.4 | 56.1 | 7 | 42.1 | 66.20 | 46.75 |
| | | Rope-pull | | | | | | | | | | 6.3 | 56.1 | 7.6 | 43.2 | 66.33 | 47.42 |
| | | Torque | | | | | | | | | | 5 | 46.2 | 6.3 | 43.5 | 54.88 | 49.55 |
| | | Post | | | | | | | | | | 6 | 30.2 | | | 32.23 | |
| | Supine | Exercise | | | | | | | | | | 5.90 | 52.80 | 6.97 | 42.93 | 62.47 | 47.91 |
| 7 | Upright | Baseline | 28 | M | 185 | 84 | 72 | 1.83 | 2.40 | 38 | 91 | not done | | | | | |
| | Supine | Baseline | 28 | M | 185 | 84 | 72 | 1.83 | 2.40 | 38 | 91 | 5 | 22 | | | 22.64 | |
| | | Ergometer | | | | | | | | | | 5.2 | 43 | 6.2 | 48.5 | 50.35 | 56.34 |
| | | Rope-Pull | | | | | | | | | | 6.2 | 38.8 | 5.9 | 39.5 | 43.42 | 44.76 |
| | | Torque | | | | | | | | | | 6.6 | 37.6 | 6.5 | 35.6 | 41.29 | 38.76 |
| | | Post | | | | | | | | | | 5.1 | 20 | | | 19.85 | |
| | Supine | Exercise | | | | | | | | | | 6.00 | 39.80 | 6.20 | 41.20 | 45.02 | 46.62 |
| 2 | Upright | Baseline | 33 | F | 125 | 57 | 64 | 1.63 | 1.61 | 36 | 58 | 6.3 | 34.6 | | | 37.70 | |
| | | Ergometer | | | | | | | | | | 6.2 | 55.3 | 7 | 57.3 | 65.40 | 67.00 |
| | | Rope-pull | | | | | | | | | | 5.8 | 66.5 | 6.5 | 64 | 80.85 | 76.59 |
| | | Torque | | | | | | | | | | 6.9 | 45.4 | 6.2 | 44.5 | 51.28 | 51.02 |
| | | Post | | | | | | | | | | 6.6 | 28 | | | 28.50 | |
| | Upright | Exercise | | | | | | | | | | 6.30 | 55.73 | 6.57 | 55.27 | 65.85 | 64.87 |
| | Supine | Baseline | 33 | F | 125 | 57 | 64 | 1.63 | 1.61 | 36 | 58 | 6.1 | 30.8 | | | 32.90 | |
| | | Ergometer | | | | | | | | | | 6 | 47.2 | 6.3 | 44.5 | 54.88 | 50.88 |
| | | Rope-pull | | | | | | | | | | 6.3 | 62.4 | 5.8 | 55.4 | 74.73 | 66.07 |
| | | Torque | | | | | | | | | | 5.8 | 38.8 | | | 43.96 | |
| | | Post | | | | | | | | | | 7.7 | 25.7 | | | 23.98 | |
| | Supine | Exercise | | | | | | | | | | 6.03 | 49.47 | 6.05 | 49.95 | 57.85 | 58.47 |
| 3 | Upright | Baseline | 37 | F | 137 | 62 | 64 | 1.63 | 1.64 | 36 | 59 | not done | | | | | |
| | Supine | Baseline | 37 | F | 137 | 62 | 64 | 1.63 | 1.64 | 36 | 59 | 4.5 | 16.1 | | | 15.45 | |
| | | Ergometer | | | | | | | | | | 5.5 | 28.7 | 5.1 | 28.3 | 30.90 | 30.90 |
| | | Rope-pull | | | | | | | | | | 5.7 | 26.3 | 7 | 25.9 | 27.44 | 25.17 |
| | | Torque | | | | | | | | | | 5.8 | 26.4 | 6.1 | 27 | 27.44 | 27.84 |
| | | Post | | | | | | | | | | 5.3 | 20.9 | | | 20.78 | |
| | Supine | Exercise | | | | | | | | | | 5.67 | 27.13 | 6.07 | 27.07 | 28.59 | 27.97 |
| 4 | Upright | Baseline | 28 | M | 160 | 73 | 72 | 1.83 | 1.91 | 38 | 73 | 28.5 | 61.8 | | | 44.36 | |
| | | Ergometer | | | | | | | | | | 28.6 | 82 | 27.9 | 82.2 | 71.13 | 72.33 |
| | | Rope-pull | | | | | | | | | | 28.9 | 100+ | 27.2 | 96.8 | | 92.71 |
| | | Torque | | | | | | | | | | 28.4 | 81.9 | 27.1 | 84.5 | 71.26 | 76.46 |
| | | Post | | | | | | | | | | 29.1 | 85.9 | | | 75.66 | |
| | Upright | Exercise | | | | | | | | | | 28.63 | 81.95 | 27.40 | 87.83 | 71.20 | 80.50 |
| | Supine | Baseline | 28 | M | 160 | 73 | 72 | 1.83 | 1.91 | 38 | 73 | 28.4 | 54.8 | | | 35.16 | |
| | | Ergometer | | | | | | | | | | 28.2 | 69.8 | 27.8 | 76.7 | 55.41 | 65.13 |
| | | Rope-pull | | | | | | | | | | 27.7 | 67.8 | 27.9 | 86.3 | 53.41 | 77.79 |
| | | Torque | | | | | | | | | | 28 | 61.8 | 29.1 | 60.6 | 45.02 | 41.96 |
| | | Post | | | | | | | | | | 29.7 | 45.6 | | | 21.18 | |
| | Supine | Exercise | | | | | | | | | | 27.97 | 66.47 | 28.27 | 74.53 | 51.28 | 61.63 |

*BMR= Basal metabolic rate

Appendix B. Data Base to Calculate Body Surface Area, Average Metabolic Rates, Mechanical Efficiency, and Energy Input of Control Subjects Exercising at Site Level

| L.D.# | Activity Level | Exercise | Gas Volume (L) (ATPS) Average | Temp. C Trial 1 | Temp. C Trial 2 | Vapor Pressure (mmHg) wet gas (Table) Trial 1 | Vapor Pressure (mmHg) wet gas (Table) Trial 2 | Time Collect (min) | Vol L/min (ATPS) Trial 1 | Vol L/min (ATPS) Trial 2 | Baro Pressure mmHg | Vol L/min (STPD) (calc) Trial 1 | Vol L/min (STPD) (calc) Trial 2 | | | |
|-----------|----------------|-----------|-------------------------------|-----------------|-----------------|---|---|--------------------|--------------------------|--------------------------|--------------------|---------------------------------|---------------------------------|-----------|-----------|--|
| 5 | Upright | Baseline | | 24 | | 22.4 | | 4 | 4.33 | | 763 | 3.88 | | | | |
| | | Ergometer | 68.27 | 23 | 24 | 21.1 | 22.4 | 4 | 18.28 | 15.8508 | 763 | 16.46 | 14.198011 | | | |
| | | Rope-Pull | 84.85 | 24 | 24 | 22.4 | 22.4 | 3.5 | 26.53 | 21.958971 | 763 | 23.76 | 19.669273 | | | |
| | | Torque | 40.16 | 24 | 24 | 22.4 | 22.4 | 4 | 10.69 | 9.3906 | 763 | 9.57 | 8.4114265 | | | |
| | | Post | | 25 | | 23.8 | | 4 | 6.43 | | 763 | 5.73 | | | | |
| | Upright | Exercise | 64.42 | 23.67 | 24.00 | 21.97 | 22.40 | 3.83 | 18.50 | 15.73 | 763.00 | 16.60 | 14.09 | | | |
| | | Supine | Baseline | | 23 | | 21.1 | | 4 | 5.26 | | 763 | 4.74 | | | |
| | | | Ergometer | 59.81 | 23 | 23 | 21.1 | 21.1 | 4 | 15.18 | 14.7186 | 763 | 13.67 | 13.251627 | | |
| | | | Rope-Pull | 54.48 | 23 | 23 | 21.1 | 21.1 | 4 | 14.05 | 13.1868 | 763 | 12.65 | 11.872499 | | |
| | | | Torque | | 22 | 23 | 19.8 | 21.1 | 4 | 9.09 | | 763 | 8.23 | | | |
| | Supine | Post | | 22 | | 19.8 | | 4 | | | 763 | | | | | |
| | | Exercise | 53.46 | 22.67 | 23.00 | 20.67 | 21.10 | 4.00 | 12.78 | 13.95 | 763.00 | 11.52 | 12.56 | | | |
| | | 6 | Upright | Baseline | | 23 | | 21.1 | | 4 | 8.52 | | 764 | 7.69 | | |
| | | | | Ergometer | 69.00 | 23 | 23 | 21.1 | 21.1 | 4 | 15.22 | 19.2807 | 764 | 13.72 | 17.38243 | |
| | | | | Rope-Pull | 58.81 | 22 | 22 | 19.8 | 19.8 | 3 | 20.65 | 18.5592 | 764 | 18.71 | 16.818062 | |
| | Torque | | | 61.07 | 22 | 23 | 19.8 | 21.1 | 4 | 12.95 | 17.5824 | 764 | 11.74 | 15.851336 | | |
| Post | | | | 23 | | 21.1 | | 4 | 10.46 | | 764 | 9.43 | | | | |
| Upright | Exercise | | 62.96 | 22.33 | 22.67 | 20.23 | 20.67 | 3.67 | 16.27 | 18.47 | 764.00 | 14.72 | 16.68 | | | |
| | Supine | | Baseline | | 24 | | 22.4 | | 4 | 8.39 | | 763 | 7.52 | | | |
| | | | Ergometer | 56.48 | 23 | 24 | 21.1 | 22.4 | 4 | 16.55 | 11.6883 | 763 | 14.90 | 10.469542 | | |
| | | | Rope-pull | 56.88 | 23 | 24 | 21.1 | 22.4 | 4 | 16.58 | 11.8548 | 763 | 14.93 | 10.61868 | | |
| | | | Torque | 52.21 | 24 | 23 | 22.4 | 21.1 | 4 | 13.72 | 12.3876 | 763 | 12.29 | 11.152953 | | |
| Supine | Post | | | 23 | | 21.1 | | 4 | 8.06 | | 763 | 7.26 | | | | |
| | Exercise | | 55.19 | 23.33 | 23.67 | 21.53 | 21.97 | 4.00 | 15.62 | 11.98 | 763.00 | 14.04 | 10.75 | | | |
| | 7 | | Upright | Baseline | | | | | | | | | | | | |
| | | | | Supine | Baseline | | 24 | | 22.4 | | 4 | 5.66 | | 764 | 5.08 | |
| | | | | Ergometer | 53.35 | 23 | 23 | 21.1 | 21.1 | 4 | 12.59 | 14.0859 | 764 | 11.35 | 12.699081 | |
| Rope-Pull | | | | 44.09 | 23 | 23 | 21.1 | 21.1 | 4 | 10.86 | 11.1888 | 764 | 9.79 | 10.087214 | | |
| Torque | | 40.03 | | 23 | 23 | 21.1 | 21.1 | 4 | 10.32 | 9.6903 | 764 | 9.31 | 8.7362474 | | | |
| Supine | | Post | | 23 | | 21.1 | | 4 | 4.96 | | 764 | 4.47 | | | | |
| | | Exercise | 45.82 | 23.00 | 23.00 | 21.10 | 21.10 | 4.00 | 11.26 | 11.66 | 764.00 | 10.15 | 10.51 | | | |
| | | 2 | Upright | Baseline | | 20 | | 17.5 | | 4 | 9.42 | | 763 | 8.61 | | |
| | | | | Ergometer | 66.20 | 20 | 20 | 17.5 | 17.5 | 4 | 16.35 | 16.7499 | 763 | 14.94 | 15.308805 | |
| | | | | Rope-pull | 78.72 | 21 | 20 | 18.7 | 17.5 | 4 | 20.21 | 19.1475 | 763 | 18.38 | 17.500125 | |
| Torque | | | | 51.15 | 20 | 20 | 17.5 | 17.5 | 4 | 12.82 | 12.7539 | 763 | 11.72 | 11.656605 | | |
| Post | | | | | 20 | | 17.5 | | 4 | 7.13 | | 763 | 6.51 | | | |
| Upright | | | Exercise | 65.36 | 20.33 | 20.00 | 17.90 | 17.50 | 4.00 | 16.46 | 16.22 | 763.00 | 15.01 | 14.82 | | |
| | | | Supine | Baseline | | 21 | | 18.7 | | 4 | 8.23 | | 763 | 7.48 | | |
| | | | | Ergometer | 52.88 | 20 | 20 | 17.5 | 17.5 | 4 | 13.72 | 12.7206 | 763 | 12.54 | 11.62617 | |
| | | | | Rope-pull | 70.40 | 20 | 20 | 17.5 | 17.5 | 4 | 18.68 | 16.5168 | 763 | 17.07 | 15.09576 | |
| | Torque | | | | 20 | | 17.5 | | 4 | 10.99 | | 763 | 10.04 | | | |
| Supine | Post | | | 20 | | 17.5 | | 4 | 5.99 | | 763 | 5.48 | | | | |
| | Exercise | | 58.16 | 20.00 | 20.00 | 17.50 | 17.50 | 4.00 | 14.46 | 14.62 | 763.00 | 13.22 | 13.36 | | | |
| | 3 | | Upright | Baseline | | | | | | | | | | | | |
| | | | | Supine | Baseline | | 20 | | 17.5 | | 4 | 3.86 | | 759 | 3.51 | |
| | | | | Ergometer | 30.90 | 20 | 20 | 17.5 | 17.5 | 4 | 7.73 | 7.7256 | 759 | 7.02 | 7.0230346 | |
| Rope-pull | | | | 26.31 | 20 | 20 | 17.5 | 17.5 | 4 | 6.86 | 6.2937 | 759 | 6.24 | 5.7213515 | | |
| Torque | | 27.64 | | 20 | 20 | 17.5 | 17.5 | 4 | 6.86 | 6.9597 | 759 | 6.24 | 6.3267855 | | | |
| Supine | | Post | | 20 | | 17.5 | | 4 | 5.19 | | 759 | 4.72 | | | | |
| | | Exercise | 28.28 | 20.00 | 20.00 | 17.50 | 17.50 | 4.00 | 7.15 | 6.99 | 759.00 | 6.50 | 6.36 | | | |
| | | 4 | Upright | Baseline | | 28 | | 28.4 | | 4 | 11.09 | | 762 | 9.71 | | |
| | | | | Ergometer | 71.73 | 25 | 26 | 23.8 | 25.2 | 4 | 17.78 | 18.0819 | 762 | 15.82 | 16.005585 | |
| | | | | Rope-pull | 46.35 | 26 | 26 | 25.2 | 25.2 | 3.5 | | 26.487771 | 762 | | 23.446224 | |
| Torque | | | | 73.86 | 28 | 26 | 28.4 | 25.2 | 3.15 | 22.62 | 24.272 | 762 | 19.81 | 21.484886 | | |
| Post | | | | | 26 | | 25.2 | | 4 | 18.91 | | 762 | 16.74 | | | |
| Upright | | | Exercise | 75.85 | 26.33 | 26.00 | 25.80 | 25.20 | 3.55 | 20.20 | 22.95 | 762.00 | 17.81 | 20.31 | | |
| | | | Supine | Baseline | | 27 | | 26.7 | | 4 | 8.79 | | 762 | 7.74 | | |
| | | | | Ergometer | 60.27 | 27 | 26 | 26.7 | 25.2 | 4 | 13.85 | 16.2837 | 762 | 12.20 | 14.413869 | |
| | | | | Rope-pull | 65.60 | 25 | 25 | 23.8 | 23.8 | 4 | 13.35 | 19.4472 | 762 | 11.88 | 17.304694 | |
| | Torque | | | 43.49 | 27 | 26 | 26.6 | 25.2 | 4 | 11.26 | 10.4895 | 762 | 9.91 | 9.2850078 | | |
| Supine | Post | | | 26 | | 25.2 | | 4 | 5.29 | | 762 | 4.69 | | | | |
| | Exercise | | 56.45 | 26.33 | 25.67 | 25.70 | 24.73 | 4.00 | 12.82 | 15.41 | 762.00 | 11.33 | 13.67 | | | |

Appendix B. Data Base to Calculate Body Surface Area, Average Metabolic Rates, Mechanical Efficiency, and Energy Input of Control Subjects Exercising at Site Level

| I.D.# | Activity Level | Exercise | %O2 expire Trial 1 | %N expire Trial 1 | %CO2 expire Trial 1 | %O2 expire Trial 2 | %N expire Trial 2 | %CO2 expire Trial 2 | %O2 inspire Trial 1 | %N inspire Trial 1 | %CO2 inspire Trial 1 | %O2 inspire Trial 2 | %N inspire Trial 2 | %CO2 inspire Trial 2 |
|-------|----------------|-----------|--------------------|-------------------|---------------------|--------------------|-------------------|---------------------|---------------------|--------------------|----------------------|---------------------|--------------------|----------------------|
| 5 | Upright | Baseline | 16 | 79.5 | 4.44 | | | | 21.2 | 78.7 | 0.09 | | | |
| | | Ergometer | 16.5 | 78.9 | 4.62 | 16 | 79.2 | 4.65 | 21.2 | 78.7 | 0.10 | 21 | 78.9 | 0.10 |
| | | Rope-Pull | 17.1 | 78.6 | 4.35 | 15.7 | 79.3 | 5.02 | 21.1 | 78.7 | 0.09 | 21 | 78.9 | 0.10 |
| | | Torque | 16 | 79.4 | 4.49 | 15.9 | 79.5 | 4.5 | 21.2 | 78.8 | 0.10 | 21.1 | 78.9 | 0.10 |
| | | Post | 16.3 | 79.4 | 4.3 | | | | 21.1 | 78.9 | 0.10 | | | |
| | Supine | Exercise | 16.53 | 78.97 | 4.49 | 15.87 | 79.33 | 4.72 | 21.17 | 78.73 | 0.10 | 21.03 | 78.90 | 0.10 |
| | | Baseline | 15.8 | 79.4 | 4.72 | | | | 21 | 78.8 | 0.10 | | | |
| | | Ergometer | 16 | 79.2 | 4.77 | 15.8 | 79.5 | 4.57 | 21 | 78.8 | 0.10 | 21 | 78.8 | 0.10 |
| | | Rope-Pull | 16.3 | 79.1 | 4.55 | 15.9 | 79.4 | 4.54 | 21 | 78.8 | 0.10 | 21 | 78.8 | 0.10 |
| | | Torque | 16.6 | 79 | 4.43 | 16.2 | 79.1 | 4.48 | 21.1 | 78.8 | 0.10 | 21 | 78.8 | 0.10 |
| 6 | Upright | Post | 15.7 | 79.8 | 4.42 | | | | 21 | 78.8 | 0.10 | | | |
| | | Exercise | 16.30 | 79.10 | 4.58 | 15.97 | 79.33 | 4.53 | 21.03 | 78.80 | 0.10 | 21.00 | 78.80 | 0.10 |
| | Supine | Baseline | 16.8 | 79.6 | 3.6 | | | | 21.1 | 78.7 | 0.08 | | | |
| | | Ergometer | 16.8 | 79.4 | 3.7 | 17.1 | 79.3 | 3.5 | 21.1 | 78.7 | 0.08 | 21.1 | 78.7 | 0.09 |
| | | Rope-Pull | 16.6 | 79.3 | 4.1 | 16.7 | 79.1 | 3.9 | 21.1 | 78.7 | 0.09 | 21.1 | 78.7 | 0.09 |
| | | Torque | 17.1 | 79.4 | 3.4 | 17 | 79.3 | 3.5 | 21.1 | 78.7 | 0.09 | 21.1 | 78.7 | 0.09 |
| | | Post | 16.9 | 79.5 | 3.5 | | | | 21.1 | 78.7 | 0.09 | | | |
| | Supine | Exercise | 16.83 | 79.37 | 3.73 | 16.93 | 79.23 | 3.63 | 21.10 | 78.70 | 0.09 | 21.10 | 78.70 | 0.09 |
| | | Baseline | 16.6 | 79.4 | 3.71 | | | | 21.1 | 78.7 | 0.10 | | | |
| | | Ergometer | 16 | 79.5 | 4.3 | 16 | 79.7 | 4.27 | 21.2 | 78.7 | 0.08 | 21.2 | 78.8 | 0.09 |
| | | Rope-pull | 16.3 | 79.5 | 4.13 | 16.2 | 79.6 | 4.11 | 21.1 | 78.8 | 0.10 | 21.2 | 78.8 | 0.09 |
| | | Torque | 16.6 | 79.3 | 4.02 | 16.2 | 79.6 | 4.17 | 21.2 | 78.8 | 0.09 | 21.2 | 78.8 | 0.09 |
| 7 | Upright | Post | 16.3 | 79.6 | 3.97 | | | | 21.2 | 78.8 | 0.09 | | | |
| | | Exercise | 16.30 | 79.43 | 4.15 | 16.13 | 79.63 | 4.18 | 21.17 | 78.77 | 0.09 | 21.20 | 78.80 | 0.09 |
| | Supine | Baseline | | | | | | | 21.1 | 78.7 | 0.10 | | | |
| | | Ergometer | 15.8 | 80.2 | 3.97 | | | | 21.1 | 78.7 | 0.10 | 21.1 | 78.8 | 0.09 |
| | | Rope-Pull | 16.3 | 79.6 | 3.95 | 16.6 | 79.4 | 3.88 | 21.1 | 78.7 | 0.10 | 21.1 | 78.8 | 0.10 |
| | | Torque | 16.4 | 79.6 | 4 | 16.8 | 79.3 | 3.75 | 21.1 | 78.7 | 0.10 | 21.1 | 78.8 | 0.10 |
| | | Post | 16.4 | 79.5 | 4.14 | 16.8 | 79.3 | 3.75 | 21.1 | 78.8 | 0.11 | 21.1 | 78.8 | 0.10 |
| | Supine | Exercise | 16 | 80 | 3.8 | | | | 21.1 | 78.8 | 0.10 | | | |
| | | Baseline | 16.37 | 79.57 | 4.03 | 16.73 | 79.33 | 3.79 | 21.10 | 78.73 | 0.10 | 21.10 | 78.80 | 0.10 |
| | | Ergometer | 18.3 | 78.8 | 3.04 | | | | 21.2 | 78.6 | 0.07 | | | |
| 2 | Upright | Rope-pull | 17.3 | 79.3 | 3.54 | 17.1 | 79.5 | 3.45 | 21.2 | 78.6 | 0.07 | 21.2 | 78.6 | 0.08 |
| | | Torque | 17.7 | 78.8 | 3.62 | 17.6 | 79 | 3.5 | 21.2 | 78.6 | 0.07 | 21.2 | 78.6 | 0.08 |
| | | Post | 17.9 | 79 | 3.1 | 18 | 79.1 | 3.02 | 21.2 | 78.6 | 0.07 | 21.2 | 78.6 | 0.08 |
| | | Exercise | 17.8 | 79.2 | 2.98 | | | | 21.2 | 78.6 | 0.08 | | | |
| | | Supine | 17.63 | 79.03 | 3.42 | 17.57 | 79.20 | 3.32 | 21.20 | 78.60 | 0.07 | 21.20 | 78.60 | 0.08 |
| | Supine | Baseline | 18.1 | 78.8 | 3.23 | | | | 21.2 | 78.8 | 0.07 | | | |
| | | Ergometer | 17.7 | 78.9 | 3.45 | 17.5 | 79.2 | 3.4 | 21.2 | 78.8 | 0.07 | 21.2 | 78.8 | 0.07 |
| | | Rope-pull | 18.2 | 78.7 | 3.23 | 17.9 | 79 | 3.22 | 21.2 | 78.8 | 0.07 | 21.2 | 78.8 | 0.07 |
| | | Torque | 18.1 | 78.8 | 3.14 | | | | 21.2 | 78.8 | 0.07 | | | |
| | | Post | 17.9 | 79.2 | 3.03 | | | | 21.2 | 78.8 | 0.07 | | | |
| 3 | Upright | Exercise | 18.00 | 78.80 | 3.27 | 17.70 | 79.10 | 3.31 | 21.20 | 78.80 | 0.07 | 21.20 | 78.80 | 0.07 |
| | | Baseline | | | | | | | 20.9 | 79.1 | 0.10 | | | |
| | | Ergometer | 16.8 | 79.3 | 3.88 | | | | 20.9 | 79.1 | 0.10 | 20.9 | 79.1 | 0.10 |
| | | Rope-pull | 16.4 | 79.6 | 4 | 16.2 | 79.8 | 4.01 | 20.9 | 79.1 | 0.10 | 20.9 | 79.1 | 0.09 |
| | | Torque | 16.4 | 79.7 | 3.95 | 16.3 | 79.8 | 3.98 | 20.9 | 79.1 | 0.10 | 20.9 | 79.1 | 0.09 |
| | Supine | Post | 16.6 | 79.7 | 3.8 | 16.5 | 79.7 | 3.75 | 20.9 | 79.1 | 0.10 | 20.9 | 79.1 | 0.09 |
| | | Exercise | 16.6 | 79.7 | 3.77 | | | | 20.8 | 79.1 | 0.08 | | | |
| | | Baseline | 16.47 | 79.67 | 3.92 | 16.33 | 79.77 | 3.91 | 20.90 | 79.10 | 0.10 | 20.90 | 79.10 | 0.09 |
| | | Ergometer | 18 | 78.7 | 3.26 | | | | 21.1 | 78.7 | 0.10 | | | |
| | | Rope-pull | 16.8 | 78.9 | 4.24 | 17.1 | 78.9 | 3.99 | 21.1 | 78.7 | 0.10 | 21.1 | 78.7 | 0.10 |
| 4 | Upright | Torque | 17.3 | 78.4 | 4.3 | 17.7 | 78.5 | 3.78 | 21.1 | 78.7 | 0.10 | 21.1 | 78.7 | 0.10 |
| | | Post | 16.9 | 79.1 | 4.04 | 17 | 79.1 | 3.87 | 21.1 | 78.7 | 0.10 | 21.1 | 78.7 | 0.10 |
| | | Exercise | 18.4 | 78.4 | 3.18 | | | | 21.1 | 78.7 | 0.10 | | | |
| | | Baseline | 17.00 | 78.80 | 4.19 | 17.27 | 78.83 | 3.88 | 21.10 | 78.70 | 0.10 | 21.10 | 78.70 | 0.10 |
| | | Ergometer | 17 | 79 | 3.98 | | | | 21.1 | 78.7 | 0.10 | | | |
| | Supine | Rope-pull | 17.2 | 78.6 | 4.1 | 16.8 | 78.9 | 4.28 | 21.1 | 78.7 | 0.10 | 21.1 | 78.7 | 0.10 |
| | | Torque | 17 | 78.9 | 4.02 | 16.9 | 78.9 | 4.23 | 21.1 | 78.7 | 0.10 | 21.1 | 78.7 | 0.10 |
| | | Post | 16.3 | 79.1 | 4.4 | 16.6 | 79 | 4.29 | 21.1 | 78.7 | 0.10 | 21.1 | 78.7 | 0.10 |
| | | Exercise | 17.2 | 78.8 | 3.9 | | | | 21.1 | 78.7 | 0.10 | | | |
| | | Baseline | 16.83 | 78.87 | 4.17 | 16.77 | 78.93 | 4.27 | 21.10 | 78.70 | 0.10 | 21.10 | 78.70 | 0.10 |

Appendix B. Data Base to Calculate Body Surface Area, Average Metabolic Rates, Mechanical Efficiency, and Energy Input of Control Subjects Exercising at Site Level

| I.D.# | Activity Level | Exercise | Volume O2 Cons. (L/min) (calc) Trial 1 | Volume O2 Cons. (L/min) Trial 2 | Volume CO2 (L/min) Product (calc) Trial 1 | Volume CO2 (L/min) Product (calc) Trial 2 | RQ (calc) Trial 1 | RQ (calc) Trial 2 | Mean RQ (calc) | O2 Cons. (kcal/L) Trial 1 | O2 Cons. (kcal/L) Trial 2 |
|-------|----------------|-----------|--|---------------------------------|---|---|-------------------|-------------------|----------------|---------------------------|---------------------------|
| 5 | Upright | Baseline | 0.209991933 | | 0.168675947 | | 0.803249648 | | | 4.801 | |
| | | Ergometer | 0.782468917 | 0.72123735 | 0.743973947 | 0.646009487 | 0.950803197 | 0.895696108 | 0.923249652 | 4.985 | 4.924 |
| | | Rope-Pull | 0.944027253 | 1.063412137 | 1.012173286 | 0.967728229 | 1.072186511 | 0.910021802 | 0.991104156 | 5.047 | 4.936 |
| | | Torque | 0.513340484 | 0.45089084 | 0.420329721 | 0.370102767 | 0.818812725 | 0.820825649 | 0.819819187 | 4.825 | 4.825 |
| | | Post | 0.282533678 | | 0.240516891 | | 0.85128574 | | | 4.875 | |
| | Supine | Exercise | 0.75 | 0.75 | 0.73 | 0.66 | 0.95 | 0.88 | 0.91 | 4.95 | 4.90 |
| | | Baseline | 0.253898771 | | 0.218849728 | | 0.861956625 | | | 4.875 | |
| | | Ergometer | 0.698141646 | 0.713805303 | 0.638452617 | 0.592347747 | 0.914502982 | 0.82984498 | 0.872173981 | 4.936 | 4.838 |
| | | Rope-Pull | 0.604759478 | 0.624481383 | 0.56301428 | 0.527138947 | 0.93097223 | 0.844122756 | 0.887547493 | 4.961 | 4.85 |
| | | Torque | 0.374619211 | | 0.35622756 | | 0.950905747 | | | 4.985 | |
| | Supine | Exercise | 0.56 | 0.67 | 0.52 | 0.56 | 0.93 | 0.84 | 0.88 | 4.96 | 4.84 |
| 6 | Upright | Baseline | 0.349021127 | | 0.270529459 | | 0.775109121 | | | 4.776 | |
| | | Ergometer | 0.615700499 | 0.723259296 | 0.496657166 | 0.592740877 | 0.806653831 | 0.819541318 | 0.813097574 | 4.813 | 4.825 |
| | | Rope-Pull | 0.872005174 | 0.758030883 | 0.750234446 | 0.640768173 | 0.860355497 | 0.845306157 | 0.852830827 | 4.875 | 4.862 |
| | | Torque | 0.491567859 | 0.675403854 | 0.388542503 | 0.540530541 | 0.790414783 | 0.80030716 | 0.795360972 | 4.788 | 4.801 |
| | | Post | 0.416142112 | | 0.321451874 | | 0.772456969 | | | 4.764 | |
| | Supine | Exercise | 0.66 | 0.72 | 0.55 | 0.59 | 0.82 | 0.82 | 0.82 | 4.83 | 4.83 |
| | | Baseline | 0.352353472 | | 0.27134904 | | 0.77010463 | | | 4.764 | |
| | | Ergometer | 0.806941498 | 0.569766267 | 0.628804713 | 0.437626835 | 0.779244486 | 0.768081336 | 0.773662911 | 4.776 | 4.764 |
| | | Rope-pull | 0.744652539 | 0.553788432 | 0.601701837 | 0.426870947 | 0.80803033 | 0.770819544 | 0.789424937 | 4.813 | 4.764 |
| | | Torque | 0.581826521 | 0.581651997 | 0.482959055 | 0.455040499 | 0.830073979 | 0.782324314 | 0.806199146 | 4.838 | 4.776 |
| | Supine | Post | 0.371131098 | | 0.281510138 | | 0.758519401 | | | 4.751 | |
| | | Exercise | 0.71 | 0.57 | 0.57 | 0.44 | 0.81 | 0.77 | 0.79 | 4.81 | 4.77 |
| 7 | Upright | Baseline | | | | | | | | | |
| | | Ergometer | 0.289530879 | | 0.196501761 | | 0.678690168 | | | | |
| | | Rope-Pull | 0.572092084 | 0.591860989 | 0.436902435 | 0.481295181 | 0.763692502 | 0.813189566 | 0.788441034 | 4.751 | 4.813 |
| | | Torque | 0.483604587 | 0.44725527 | 0.381692954 | 0.368183293 | 0.789266612 | 0.823206159 | 0.806236386 | 4.788 | 4.825 |
| | | Post | 0.454856873 | 0.38735501 | 0.375058209 | 0.31887303 | 0.824563135 | 0.823206159 | 0.823884647 | 4.825 | 4.825 |
| | Supine | Exercise | 0.50 | 0.48 | 0.40 | 0.39 | 0.79 | 0.82 | 0.81 | 4.79 | 4.82 |
| | | Baseline | 0.254426306 | | 0.255809224 | | 1.005435438 | | | 5.047 | |
| | | Ergometer | 0.611013925 | 0.664822852 | 0.518542411 | 0.51590674 | 0.848658908 | 0.776006328 | 0.812332618 | 4.862 | 4.776 |
| | | Rope-pull | 0.653270806 | 0.648885056 | 0.652545833 | 0.598504288 | 0.998890241 | 0.922357947 | 0.960624094 | 5.047 | 4.948 |
| | | Torque | 0.399318438 | 0.388731472 | 0.3550395 | 0.342704195 | 0.889113716 | 0.881596215 | 0.885354966 | 4.911 | 4.899 |
| | Supine | Post | 0.231985333 | | 0.188879614 | | 0.814187741 | | | 4.813 | |
| | | Exercise | 0.55 | 0.57 | 0.51 | 0.49 | 0.91 | 0.86 | 0.89 | 4.94 | 4.87 |
| 2 | Upright | Baseline | 0.231874304 | | 0.236362194 | | 1.019354839 | | | 5.047 | |
| | | Ergometer | 0.442246206 | 0.442679711 | 0.423825645 | 0.38715147 | 0.958347726 | 0.874563392 | 0.916455559 | 4.998 | 4.887 |
| | | Rope-pull | 0.507627539 | 0.506282683 | 0.539539518 | 0.475516451 | 1.062864948 | 0.939231119 | 1.001048033 | 5.047 | 4.973 |
| | | Torque | 0.311350057 | | 0.308336992 | | 0.990322581 | | | 5.035 | |
| | | Post | 0.186679334 | | 0.162157684 | | 0.868642932 | | | 4.887 | |
| | Supine | Exercise | 0.42 | 0.47 | 0.42 | 0.43 | 1.00 | 0.91 | 0.96 | 5.03 | 4.93 |
| 3 | Upright | Baseline | | | | | | | | | |
| | | Ergometer | 0.145827853 | | 0.132735354 | | 0.910219489 | | | 4.936 | |
| | | Rope-pull | 0.325314776 | 0.343072133 | 0.273898349 | 0.274600653 | 0.84194869 | 0.800416667 | 0.821182678 | 4.85 | 4.801 |
| | | Torque | 0.290504769 | 0.273764136 | 0.24008486 | 0.222560572 | 0.826440338 | 0.812964675 | 0.819702507 | 4.838 | 4.813 |
| | | Post | 0.278032829 | 0.288408636 | 0.230730904 | 0.231560349 | 0.829869283 | 0.802889789 | 0.816379536 | 4.838 | 4.801 |
| | Supine | Exercise | 0.205790926 | | 0.174256019 | | 0.846762402 | | | 4.862 | |
| | | Baseline | 0.30 | 0.30 | 0.25 | 0.24 | 0.83 | 0.81 | 0.82 | 4.84 | 4.81 |
| | | Ergometer | 0.300948403 | | 0.306773211 | | 1.019354839 | | | 5.047 | |
| | | Rope-pull | 0.688879048 | 0.648805802 | 0.65507747 | 0.622617249 | 0.950932493 | 0.95963576 | 0.955284126 | 4.985 | 4.998 |
| | | Torque | 0.784599424 | | 0.862821031 | | 1.099696233 | 0.549848117 | | 5.407 | |
| 4 | Upright | Baseline | 0.853077874 | 0.903921283 | 0.780343032 | 0.80998019 | 0.914738333 | 0.896073812 | 0.905406072 | 4.936 | 4.924 |
| | | Ergometer | 0.438580912 | | 0.515668697 | | 1.175766395 | | | 5.407 | |
| | | Rope-pull | 0.77 | 0.78 | 0.72 | 0.77 | 0.93 | 0.99 | 0.80 | 4.96 | 5.11 |
| | | Torque | 0.323565115 | | 0.3003117 | | 0.928133739 | | | 4.961 | |
| | | Post | 0.472387782 | 0.627525286 | 0.487854058 | 0.602499732 | 1.032740634 | 0.960120246 | 0.99643044 | 5.407 | 4.998 |
| | Supine | Exercise | 0.493539981 | 0.736076138 | 0.465780717 | 0.714683843 | 0.94375478 | 0.970937388 | 0.957346084 | 4.973 | 5.01 |
| | | Baseline | 0.486351093 | 0.425293468 | 0.426167979 | 0.389041825 | 0.876255826 | 0.914760874 | 0.89550835 | 4.899 | 4.936 |
| | | Ergometer | 0.184038551 | | 0.178095292 | | 0.967706446 | | | 5.01 | |
| | | Rope-pull | 0.48 | 0.60 | 0.46 | 0.57 | 0.95 | 0.95 | 0.95 | 5.09 | 4.98 |
| | | Torque | | | | | | | | | |

Appendix B. Data Base to Calculate Body Surface Area, Average Metabolic Rates, Mechanical Efficiency, and Energy Input of Control Subjects Exercising at Site Level

| I.D.# | Activity Level | Exercise | Metabolic Rate (kcal/h) (calc) Trial 1 | Metabolic Rate (kcal/h) (calc) Trial 2 | Mean Metabolic Rate (kcal/h) (calc) | Energy Input kpm/hr (kg m/h) | Energy Output (kpm/4 min) | Energy Output (kpm/h) | % Mech. Efficiency | Net Energy Expenditure kcal/h | Energy - sitting or standing upright kcal/h | Mean energy - sitting or standing upright kcal/h | |
|-------|----------------|-----------|--|--|-------------------------------------|------------------------------|---------------------------|-----------------------|--------------------|-------------------------------|---|--|----|
| 5 | Upright | Baseline | 60.49 | | 60 | 25793 | | | | | 154 | 17 | 24 |
| | | Ergometer | 234.04 | 213.08 | 224 | 95326 | | | | | 230 | 120 | 71 |
| | | Rope-Pull | 285.87 | 314.94 | 300 | 128093 | | | | | 70 | 28 | 44 |
| | | Torque | 148.61 | 130.53 | 140 | 59514 | 171.4 | 2571 | 4 | | | | |
| | | Post | 82.64 | | 83 | 35238 | | | | | | | |
| | Supine | Exercise | 222.84 | 219.52 | 221 | 94311 | | | | | | | |
| | | Baseline | 74.27 | | 74 | 31667 | | | | | 137 | | |
| | | Ergometer | 206.76 | 207.20 | 207 | 88257 | | | | | 111 | | |
| | | Rope-Pull | 180.01 | 181.72 | 181 | 77122 | 171.4 | 2571 | 5 | 42 | | | |
| | | Torque | 112.05 | | 112 | 47778 | | | | | | | |
| 6 | Upright | Exercise | 166.27 | 194.46 | 167 | | | | | | | | |
| | | Baseline | 100.02 | | 100 | 42647 | | | | | 108 | -3 | |
| | | Ergometer | 177.80 | 209.38 | 194 | 82548 | | | | | 153 | 51 | |
| | | Rope-Pull | 255.06 | 221.13 | 238 | 101525 | 171.4 | 2571 | 4 | 83 | 0 | | |
| | | Torque | 141.22 | 194.56 | 168 | 71587 | | | | | | | |
| | Supine | Post | 118.95 | | 119 | 50720 | | | | | | | |
| | | Exercise | 191.36 | 208.36 | 200 | | | | | | | | |
| | | Baseline | 100.72 | | 101 | 42946 | | | | | 112 | | |
| | | Ergometer | 231.24 | 162.86 | 197 | 84022 | | | | | 102 | | |
| | | Rope-pull | 215.04 | 158.29 | 187 | 79595 | 171.4 | 2571 | 4 | 83 | | | |
| 7 | Upright | Torque | 168.89 | 166.68 | 168 | 71544 | | | | | | | |
| | | Post | 105.79 | | 106 | 45111 | | | | | | | |
| | | Exercise | 205.06 | 162.61 | 184 | | | | | | | | |
| | | Baseline | | | | | | | | | 76 | | |
| | | Ergometer | 163.08 | 170.92 | 167 | 71208 | | | | | 43 | | |
| | Supine | Rope-Pull | 138.93 | 129.48 | 134 | 57225 | 171.4 | 2571 | 5 | 31 | | | |
| | | Torque | 131.68 | 112.14 | 122 | 51982 | | | | | | | |
| | | Post | | | | | | | | | | | |
| | | Exercise | 144.56 | 137.51 | 141 | | | | | | | | |
| | | Baseline | 77.05 | | 77 | 32852 | | | | | 127 | 53 | |
| 2 | Upright | Ergometer | 178.24 | 190.51 | 184 | 78619 | | | | | 137 | 43 | |
| | | Rope-pull | 197.82 | 192.64 | 195 | 83247 | 171.4 | 2571 | 5 | 58 | 22 | | |
| | | Torque | 117.66 | 114.26 | 116 | 49447 | | | | | | | |
| | | Post | 66.99 | | 67 | 28566 | | | | | | | |
| | | Exercise | 164.58 | 165.81 | 165 | | | | | | | | |
| | Supine | Baseline | 70.22 | | 70 | 29940 | | | | | 73 | | |
| | | Ergometer | 132.62 | 129.80 | 131 | 55949 | | | | | 95 | | |
| | | Rope-pull | 153.72 | 151.06 | 152 | 64980 | 171.4 | 2571 | 6 | 36 | | | |
| | | Torque | 94.06 | | 94 | 40107 | | | | | | | |
| | | Post | 54.74 | | 55 | 23340 | | | | | | | |
| 3 | Upright | Exercise | 126.80 | 140.43 | 126 | | | | | | | | |
| | | Baseline | | | | | | | | | | | |
| | | Ergometer | 43.19 | | 43 | 18416 | | | | | 38 | | |
| | | Rope-pull | 94.67 | 98.83 | 97 | 41252 | | | | | 23 | | |
| | | Torque | 84.33 | 79.06 | 82 | 34834 | 171.4 | 2571 | 7 | 23 | | | |
| | Supine | Post | 80.71 | 83.08 | 82 | 34919 | | | | | | | |
| | | Exercise | 60.03 | | 60 | | | | | | | | |
| | | Baseline | 86.57 | 86.99 | 87 | | | | | | | | |
| | | Ergometer | 97.63 | | 98 | 41631 | | | | | 128 | 30 | |
| | | Rope-pull | 206.04 | 194.56 | 200 | 85410 | | | | | 182 | 70 | |
| 4 | Upright | Torque | 254.54 | | 255 | 108536 | 171.4 | 2571 | 2 | 187 | 125 | | |
| | | Post | 252.65 | 267.05 | 260 | 110800 | | | | | | | |
| | | Exercise | 142.28 | | 142 | | | | | | | | |
| | | Baseline | 152.90 | 238.72 | 238 | | | | | | | | |
| | | Ergometer | 96.31 | | 96 | 41068 | | | | | 98 | | |
| | Supine | Rope-pull | 153.25 | 188.18 | 171 | 72794 | | | | | 112 | | |
| | | Torque | 147.26 | 221.26 | 184 | 78570 | 171.4 | 2571 | 4 | 62 | | | |
| | | Post | 142.96 | 125.95 | 134 | 57332 | | | | | | | |
| | | Exercise | 55.32 | | 55 | | | | | | | | |
| | | Baseline | 147.82 | 178.47 | 163 | | | | | | | | |

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| 13. ABSTRACT (Maximum 200 words) This contractor report documents the ground-based study that tested the hypothesis that metabolic rates during supine and upright upper-body exercises are similar (mean value of 200 kcal/h). Six subjects each performed supine or upright exercise at three exercise stations, a hand-cycle ergometer, a rope-pull device, and a torque wrench. After a baseline measurement of the metabolic rate at rest, the metabolic rate was measured twice at each exercise station. The mean metabolic rates (kcal/h) during supine (n=6) and upright control (n=4) exercise stations were not significantly different except for the rope-pull station, 153.5 ± 16.6 (supine) as compared to 247.0 ± 21.7 (upright), p<0.05. This difference may be due in part to an increased mechanical efficiency of supine exercises (15.0 ± 0.7%) as compared to that of upright exercises (11.0 ± 1.08%), p<0.05. The net energy input was significantly smaller for the supine rope-pull exercise (64 ± 18) as compared to upright (176 ± 20). The relationship between best-rest exercises, metabolic rates, and the incidence of decompression sickness (DCS) should be examined to determine the true risk of DCS in spaceflight extravehicular activities. | | | | |
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